CrIS Optical System Design

K. Stumpf and J. Overbeck

ITT Aerospace/Communications Div. P.O. Box 3700 Fort Wayne, IN 46801

ABSTRACT

The CrIS (Cross-track Infrared Sounder) instrument collects IR spectral radiance data to calculate calibrated atmospheric temperature, pressure, and moisture profiles for the NPOESS (National Polar-orbiting Operational Environmental Satellite System) program. CrIS features a Michelson Interferometer with three spectral bands (SWIR to LWIR), each with a 3x3 array of circular sensing apertures at the focal plane. The optical design includes a folded Gregorian telescope after the interferometer, a field stop to define the sensing aperture array, and collecting optics to place the interferogram energy onto the photovoltaic HgCd detectors. Many trade studies and analyses were performed to determine the design of the optical system, including telescope configuration, pupil locations, elimination of channelled spectra, polarization sensitivity, stray energy rejection, and compact packaging. This paper will describe the trade studies and analysis performed during the design of the CrIS instrument optics.

Keywords: NPOESS, CrIS, sounder, FTS, interferometer

1. CRIS SYSTEM DESCRIPTION

The CrIS mission is to collect upwelling infrared radiance at very high spectral resolution, with excellent radiometric precision, and known geo-location. This data is then merged with microwave data from other sensors on the NPOESS platform to construct highly accurate temperature, moisture, and pressure profiles of the earth's atmosphere. These data will greatly enhance weather prediction models. Orbit parameters and scan angles are specified to obtain global coverage on a daily basis.

CrIS is a Fourier Transform Spectrometer (FTS) instrument. A Michelson interferometer is positioned in front of an 80 mm entrance pupil diameter, 254 mm focal length telescope. Forward of the focal plane, the field is split into three different wavelength bands with dichroic beamsplitters. The field of regard of each band is 3.1 degrees. The field of regard is divided into nine circular Fields Of View (FOV) as shown in figure 1-1

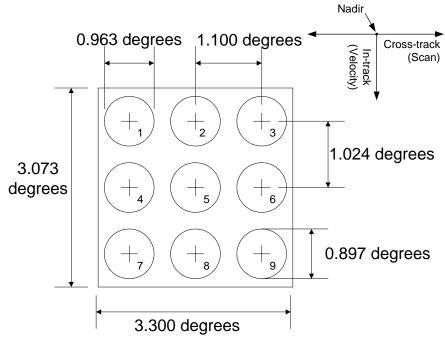


Figure 1-1 FOV definitions

The ground footprint of each FOV at nadir is approximately 14 km. Note that the angular subtent is slightly different in the along and across track directions. This is anamorphism caused by wedged elements in the optical train.

Condenser optics behind the field stop defining each FOV place an image of the exit pupil onto the photovoltaic HgCdTe detector. The detectors are cooled to 81 K by a passive radiative cooler.

Figure 1-2 shows the overall CrIS instrument. The scan mirror steps to 32 locations including space and a self contained blackbody for calibration of the system.

2. OPTICAL REQUIREMENTS

The customer specified only the required performance in terms of environmental measurements to be made and the accuracy of each measurement. The instrument requirements were generated by developing an end to end performance model, and varying sensor parameters iteratively until performance met the requirements of the Environmental Data Records (EDRs).

Table2.1 CrIS Optical Parameters

Sensor Parameter	Guaranteed Value	Sensor Parameter	Guaranteed Value
LWIR Band	650-1095 cm ⁻¹	LWIR Band-Average NEdN	0.132
MWIR Band	1210-1750 cm ⁻¹	(mW / m ² sr cm ⁻¹)	
SWIR Band	2155-2550 cm ⁻¹	MWIR Band-Average NEdN	0.044
LWIR Spectral Resolution	< 0.625 cm ⁻¹	(mW / m ² sr cm ⁻¹) SWIR Band-Average NEdN	0.006
MWIR Spectral Resolution	< 1.25 cm ⁻¹	(mW / m ² sr cm ⁻¹)	0.006
SWIR Spectral Resolution	< 2.5 cm ⁻¹	Absolute Radiometric	< 0.45% (LWIR
Number of FOVs	3 x 3	Uncertainty	< 0.6% (MWIR
FOV Diameter (Round)	14 km		< 0.8% (SWIR
FOV Motion (Jitter)	< 50 urad / axis	ILS Uncertainty	<1.5% FWHM
Mapping Accuracy	< 1.45 km	Spectral Accuracy	< 5 ppm

(Add aperture size, polarization, crosstalk, co-registrationetc. to table)

Each FOV is quite large (14 km) relative to the diffraction limited performance capability of the optical system (approx. 0.3 km). This results in image quality requirements which are not very stressing. The algorithms are sensitive to geometrical mismatch between bands and crosstalk between FOVs within a band, but not very sensitive to absolute optical quality. The telescope alone is capable of diffraction limited performance. The end to end optical performance is relatively poor by most standards. The extra error is arising from design features to eliminate stray radiation from strong ghost reflections, and eliminating channeled spectra. Also, the telescope has field curvature and the baseline design utilizes a flat field stop as a cost saving measure.

3. OPTICAL DESIGN

Figure 3-1 shows an optical schematic of the CrIS system. The CrIS design is modularized as shown by the dotted lines in the figure. Figure3-2 shows an exploded view of all 9 of the CrIS modules. The optical bench module provides the structural anchor for all other modules except the processing/control electronics module (PCE) and the scene selection module (SSM).

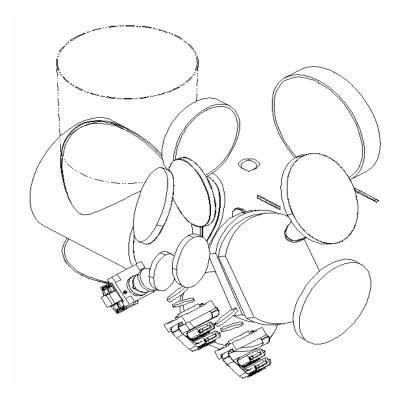


Figure 3-1 CrIS Optical Schematic

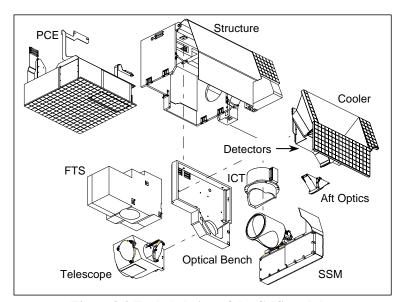


Figure 3-2 Exploded view of the CrIS modules

The scan mirror (SSM module) has a large (+xx, -yy) degrees across track scan and a small angle (0.08) degree flexure mechanism for along track scanning.

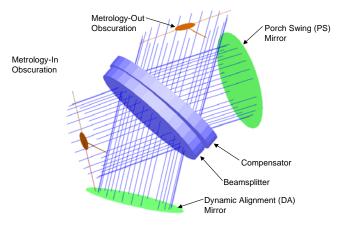


Figure 3-3 Interferometer module

Figure 3-3 shows the internal optical components of the interferometer. The angle of incidence on the beamsplitter and compensation plates is kept as small as possible to minimize polarization effects. Both plates and the airspace between them are wedged slightly to eliminate the strong ghost reflections due to the high reflectance of the beamsplitter. Also, the wedge of one plate must be slightly different from the other to prevent the output beams from being tilted relative to one another. This wedge produces a large amount of lateral chromatic aberration. This is corrected with the input fold mirror (wedged rear surface mirror) of the telescope module.

The interferometer is scanned with a "PorchSwing" mechanism and any tilt errors due to this mechanism or vibration are compensated with the dynamic alignment mirror. The metrology input and output obscurations are the locations of the diode laser distance measuring interferometer and the EO tip/tilt measuring device.

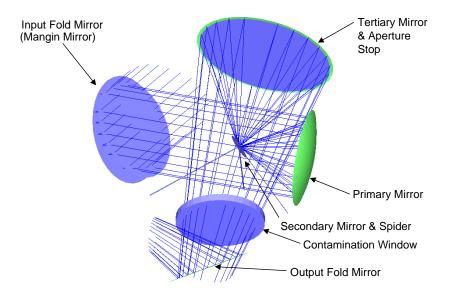


FIGURE 3-4 Telescope Module

Figure 3-4 shows the telescope module; a folded Gregorian design. Many design forms were considered. Because the optical performance requirements are not very stringent, several optical design options provided acceptable performance. The folded Gregorian design was chosen because of its diffraction limited performance and good stray light suppression,

in addition to providing excellent packaging because of its almost square form factor. Because of severe volume constraints, packaging was a very important issue. Many design iterations and trade studies were driven solely by packaging issues. Another important feature of this design is that it lends itself to diamond turning of the optical surfaces on Aluminum substrates. This makes the telescope inherently athermal and very simple to align and assemble as a module. The fabrication of the telescope for the first engineering model (EDU-1) was flawlessly executed in a very short time (x weeks).

The primary and tertiary mirrors are centered conics. The "secondary" is a fold flat near the primary focus. Note that it obscures both input and output beams. The aperture stop of the system is located at the tertiary. It is also the exit pupil. The entrance pupil is located near the input fold mirror (xx.x mm in front of the primary). The input fold mirror is a ZnSe wedge with aluminum coating on the rear surface. As was previously mentioned, this wedge corrects the lateral chromatic aberration produced by the wedged beamsplitter and compensating plates in the interferometer. The contamination window, as its name implies, prevents contaminants from migrating between modules.

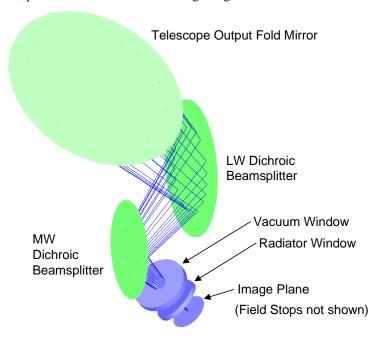


Figure 3-5 Aft Optics

The function of the Aft Optics Module is to split the output beam into the three spectral regions required of the instrument, as shown in figure 3-5. The symmetrical arrangement of dichroic beamsplitters athermalizes the module. Three field stops define the 3x3 FOV array for each wavelength band. The vacuum window is required to allow cooled operation of the detectors when the instrument is being tested in ambient conditions during integration. The region from the vacuum window to the detectors can be evacuated, preventing condensation on any surfaces during the test. The radiator window prevents excessive radiative loads from reaching the "patch", which in operation is the cooled region of the radiative cooler.

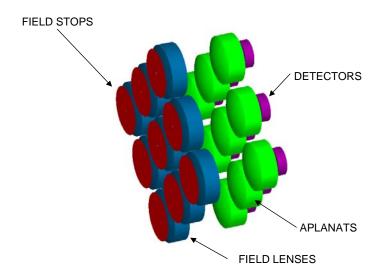


Figure 3-6 Detector optics module

The energy transmitted by each FOV must be placed on its respective detector with the collecting optics as shown in figure 3-6. The current baseline has Each FOV with its own two-element condenser lens with all spherical surfaces. The energy transmitted by the 4.3 mm diameter FOV is placed on the central 0.92 mm of the 1 mm diameter HgCdTe detector. The exit pupil is imaged onto the detector with a magnification of xx.x. The magnification is limited by the ray angles entering the detector.

Smaller detectors would benefit system performance by lowering leakage current and 1/f noise in the detector, and to some extent, the detector manufacturing yield. The size of the detector is currently limited by the ray angles into the detector whose rear surface is the sensitive area. A single element condenser lens has been designed which has an asphere on the front surface. It performs a bit better than the two element design. The best performing single element condenser design would be in optical contact with the detector substrate. This type of upgrade will probably occur on the next build.

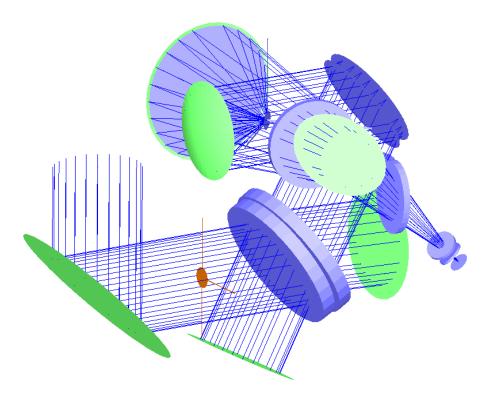


Figure 3-7 Overall CrIS Instrument

Figure 3-7 shows how the optics fit into the almost rectangular mechanical envelope. Virtually no volume is wasted. The packaging is very efficient.

4. PERFORMANCE ISSUES

1. Channelled Spectra

Multiple reflections off of the surfaces of a wedged transmitting plate interfere with each other and the transmitted beam, i.e., it acts as a form of Fabry Perot filter. This interference is referred to as channelled spectra. (insert reference). These channelled spectra show up as an intensity modulation in the final interferogram. To eliminate the channelled spectra a few waves of wedge are required on each of the transmissive components (windows and dichroic beamsplitters). This wedge in the components will reduce the modulation between the parallel plates to an acceptable level but at the cost of some optical performance.

2. Polarization

The instrument polarization sensitivity is also a concern. Since the scan mirror range is approximately 135°, any polarization of the incoming radiation off of the scan mirror will cause the instrument to act like a polarization analyzer. If this happens then there will be an induced intensity variation due to the scan mirror rotating. To eliminate this effect the polarizing properties of the scan mirror need to be minimal and well understood. To reduce this factor in the performance the scan mirror utilizes a gold coating, which has low polarization inducing properties. This gives the instrument very good polarization performance for unpolarized input. Figure 4-1 shows the calculated intensity changes due to polarization over the full CrIS scan range. The worst case intensity change is less than 0.1%.

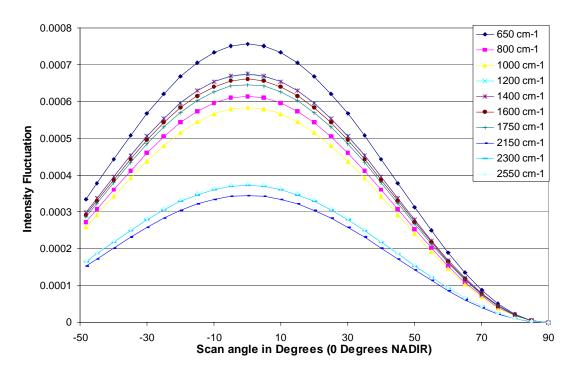


Figure 4-1 Sensor polarization

3. Tilt correction

The modulation efficiency of the interferometer is based on a number of factors in the interferometer module. One of these factors is the tilt in the wavefronts between the different arms of the interferometer. If the wavefront from one arm of the interferometer is tilted with respect to the other, the interferogram modulation is decreased by a known amount (include reference). Referring to figure 3-3, note that since the beamsplitter and compensator are wedged there is an induced tilt in the wavefront of both arms that is wavelength dependent.

The CrIS interferometer metrology aligns the interferometer beams at a wavelength of 1.55 microns. Because of the wedges, the output beams at the operational wavelengths are tilted with respect to one another by 91 microradians. If uncorrected, this would cause a 30% reduction in interferogram modulation. At first glance it would appear that the symmetry in the interferometer would preclude correcting this error. However, note that the arm with the dynamic alignment mirror traverses the beamsplitter plate twice and the compensating plate once. The arm with the porch swing traverses the compensator plate twice and the beamsplitter plate once. This allows tilting one beam relative to the other by varying the wedge of one of the plates. Perfect beam alignment was accomplished at 10 microns wavelength and the slight residual at other wavelengths is negligible (less than 0.07 microradians at 15.4 microns). This correction was accomplished by keeping the beamsplitter wedge at 0.7 degrees and reducing the compensator plate wedge to 0.6856 degrees.

5. CONCLUSION

In this paper the aspects of the CrIS optical design have been presented. The heart of the CrIS sensor is the Michelson interferometer and the remaining portions of the sensor define the pupils and deliver the interferogram to the focal planes. Wedging and tilting of various components has aided to maintain the quality of the interferogram while enclosing the system in a compact package.